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Jørgensen, Pelle Morten Thomas; Jacobsen, Peter

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Improving blood sample logistics using simulation

Pelle Jørgensen (pemj@dtu.dk)
Technical University of Denmark

Peter Jacobsen
Technical University of Denmark

Abstract

Using simulation as an approach to display and improve internal logistics and handling at hospitals has great potential. This research will show how a simulation model can be used to evaluate changes made to two different cases of transportation of blood samples at a hospital, by evaluating different scenarios against the current situation.

The simulation showed that big potential could be obtained by changing the current approach, implementing a pneumatic tube system showed that a reduction in transportation of up to 35 % could be obtained.

Keywords: Hospitals, logistics, optimisation

Introduction

The healthcare systems in most of the developed countries are experiencing increased pressure due to the demographic development (OECD, 2007). Concurrently the financial crisis has resulted in many countries having to make big cutbacks on their health care spending. As a consequence hospital managers need to make their hospitals more efficient in order to cope with the increased intake of patients and less funding. One approach used in making the hospitals more efficient is looking at the procedures performed, and analyze whether they can be performed in a more efficient manner. In this regard the internal logistics at hospitals is an area where it is possible to make changes in order to improve the efficiency of hospitals.

One of the most important tools in diagnosing and monitoring patient's illnesses and diseases are analysis of the patient's blood. As a consequence it is of utmost importance that the blood drawn from the patient is analyzed as fast as possible and that the result is completely reliable. The development of blood testing equipment has therefore undergone tremendous development, and currently it takes less than half an hour to make most of the analysis for a patient. In many cases the time it takes to do the analysis is no longer the process that take up most of the time spent, from the blood is drawn from the patient until the doctor receives the result and diagnosis the patient. In an efficiency manner this has the unwanted outcome that patients are filling up beds unnecessarily, and thereby is an extra cost to the hospitals.

Hospitals therefore have a large interest in getting an analysis of their logistical system related to the blood samples, in order to determine where the system can be improved, and what the consequences of the improvements will have on the entire system. One way of doing this is using simulation or modelling tools.

Simulation and modelling was originally designed as a tool for the production industries, but it has also been widely used within health care (Brailsford et al., 2009, Fone et al., 2003, Forsberg et al., 2011). The focus of the simulation research has been related to many different areas but with most focus on areas such as hospital scheduling, planning and resource utilization. Doing simulation studies in health care is therefore not a new topic. The interesting part is however that only a few of the studies have actually led to implementations of the results discovered in the simulation, according to the findings made by Brailsford et. al (2009) "Each modelling study was rated according to a three-level scale of implementation: 1: Suggested (theoretically proposed by the authors); 2: Conceptualised (discussed with a client organisation); 3: Implemented (actually used in practice). The number of articles rated in each category was Suggested 171 (50%); Conceptualised 153 (44.7%); Implemented 18 (5.3%)."

It is therefore very interesting to look at research that was followed by implementations, and exploit what convinced the hospital managers to implement the changes. The focus of this research is to show how a simulation model displaying an internal logistical system at a hospital can be created and used in terms of making the logistics more efficient.

Blood Testing

The earlier a disease or illness is diagnosed the better treatment doctors can give their patients. Since blood analysis is a crucial part in the diagnosing of patients, the time it takes from blood is drawn until result is received by doctor can have a great influence on the patient treatment. Analysis of blood samples have improved greatly over the last decades, both in terms of the accuracy of the analysis, but also in terms of how long time the analysis takes before result is ready. Earlier an analysis of a blood samples could take many hours or even days, but within the last decade the time of analysis has been decreased to take less than one hour, sometimes as short as 15 minutes. This constitutes completely new requirements to the time spent on the other parts of the blood sample logistical system. From being a part of the system that took a relatively short time, the transportation process is in many cases the part that takes the longest time. Hence there is a great demand for exploring new approaches of doing the transportation, in order to cut down on the time and thereby reducing the diagnosis time for patients.

At Danish hospitals there are two groups of patients that get their blood tested and analyzed as part of their diagnosis and treatment, and where it is very important that the result of the test is available as fast as possible.

The fist group are the patients that arrives at the emergency department and where the blood test will constitute a crucial part in the diagnosis of the patients illness and thereby the treatment that the patient should undergo. When a patient arrives in the emergency department in Denmark the patient is diagnosed and initial treatment is started. When the diagnose has been established then the patient will be sent to the department which is specialized in treating patients with this particular type of disease or with a disease in that particular part of the body. It is therefore very important that the diagnosis of the patients can be done as soon as possible.

The second group of patients is the hospitalized patients. Each of the departments at Danish hospitals has hospitalized patients. These patients have some disease that is so severe that the patient needs to stay at the hospital or need to undergo some recovery after treatment that needs to be monitored at the hospital. In both of the cases analysis of the blood is a very important tool in the monitoring of disease and recovery. All samples are taken on blood taking rounds, meaning that a very long time can pass from the blood samples taken in the beginning are delivered to the laboratory.

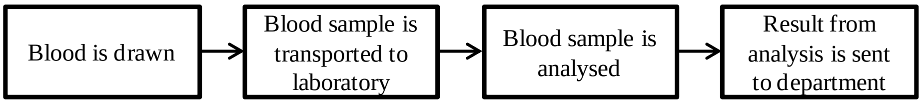

Figure 1: Overall phases involved in taking blood samples

Each of the overall phases consists of many different processes that depend on the patient type, and the technology used in performing the phase. The overall phases are the phases that the blood samples have to go through from sample is drawn until result is ready for the doctor to state diagnosis.

Why simulating blood sample logistics?

The research presented in this paper has a theoretical and a practical aim. The theoretical aim is to test the feasibility of using simulation to address logistical challenges in health care settings. Simulation tools have originally been developed to model industrial systems for analyze, optimize and implement new ideas, but simulation is also being widely used to simulate various health care systems. Therefore it is necessary to address the logistical system of a hospital in the same manner as a logistical system would be in an industrial setting. This has the implication that health care personnel doesn't consider hospitals as an institution that can be compared with a factory, airport etc. As an outcome there is a high risk of the personnel having doubts about the obtained results. Consequently it is very important to consider this issue in the construction phase of the simulation, and therefore interesting to elaborate on in retrospect.

The practical aim is in relation to the two cases. The hospitals responsible for each of the cases are very interested in getting an analysis of their current state, as well as having an evaluation of the effect of implementing different changes.

As a consequence of the two aims of the research, four overall points are used as the guidelines in the research.

1. In which parts of the system is the major time consumption?
2. Which of these processes is it possible to change?
3. Identify different technologies that can perform the process.
4. Determine the effect of making the changes to the system.

Methodology

All the data used in the simulations were provided by the two hospitals involved in the project. Further all the results obtained from the simulations were reviewed by and approved by the hospitals.

The methodology used in this research can be perceived as empirical research (Karlsson, 2009) within quantitative modelling. The aim of the research is to give hospital managers a basis for making the most optimal solution based on the situation they are in. The research takes it starting point in the current situation of two specific logistical systems.

A value stream mapping of the system was then created to pinpoint the non-value adding processes of the system and which of these takes the longest time. The next step was in collaboration with the personnel of the hospital to identify different technologies that can perform or even eliminate the non-value adding processes. Using the different technological possibilities as the offset, it is then possible to create various scenarios of how the logistical system will be affected based on the implementation of the technology. For each of the technological implementations, scenarios was created corresponding to possible resource use.

To create all the different scenarios a simulation tool was used. First a simulation for the current situation was created. This model was presented to the personnel at the hospital in order to validate the results, as well as convince the personnel of the applicability of simulation in describing their hospital. Using the initial model as a starting point, models were developed for each technological possibility. For each technology the optimal use of resources was determined, e.g. the optimal numbers of AGVs.

In creating the simulation models large amounts of data was used. The model was developed so it exactly matched the layout of the actual hospital. Using a detailed blueprint of the hospital, it was possible to get an exact layout of the different floors at the hospital with exact distances. Further due to extensive on-site observations the time used in performing clinical tasks were also included in the simulation model, as well as velocity of personnel, time used riding and waiting for elevators.

The data used were collected by the laboratory personnel performing the blood test, data extracted from the databases at the hospitals, and people from industry with knowledge regarding the different technologies.

In both cases a simulation model corresponding to the current situation was constructed, tested and determined whether it showed the correct picture. This ensured that the new simulation models showed an accurate picture of the consequences of implementing new technology.

Description of particular simulation cases

The first case relates to blood samples taken in the emergency department (emergency case). All the blood samples are acute, meaning that it is not known when and how many samples need testing. After a patient arrives at the emergency department he/she is registered, and the nurse at the reception makes a triage (an assessment) of how critically ill the patient is. After the triage the patient will undergo the first test in order to give the patient the correct diagnosis. The blood sample is a large part of this, and for the case hospital approximately 90 patients are diagnosed in the emergency department each day using blood samples. The processes involved in the

The processes involved in the transportation of blood samples between emergency department and laboratory are shown in figure 2.

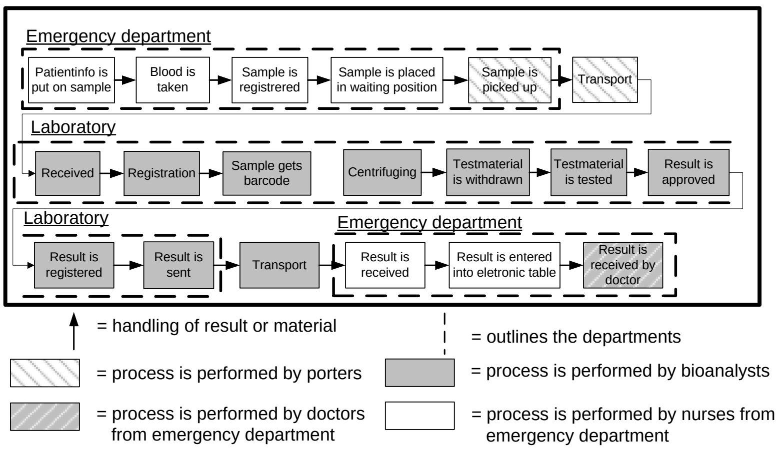

Figure 2: Process map for the blood samples taken in the emergency department

The major purpose of this system is to secure that the emergency department can get a result as soon as possible, so the patient can be diagnosed as soon as possible and thereby start the treatment. As a result of this, the simulation will be concerned with the process from blood samples are taken until result is received in emergency department.

The second case is the blood samples taken at the wards (wards case). As a very important tool in the monitoring of patients conditions the doctors at the wards use blood test. Therefore each morning biomedical analysts from the laboratory will go to the different wards and draw blood samples from the patients that the doctors require. The previous day doctors at the wards decides which patients needs to have blood samples taken, and this information is given to the laboratory, that makes blood glasses with labels ready for all the patients. There are approximately 140 patients that have blood samples taken. The processes involved in blood samples taken at the wards are shown in figure 3.

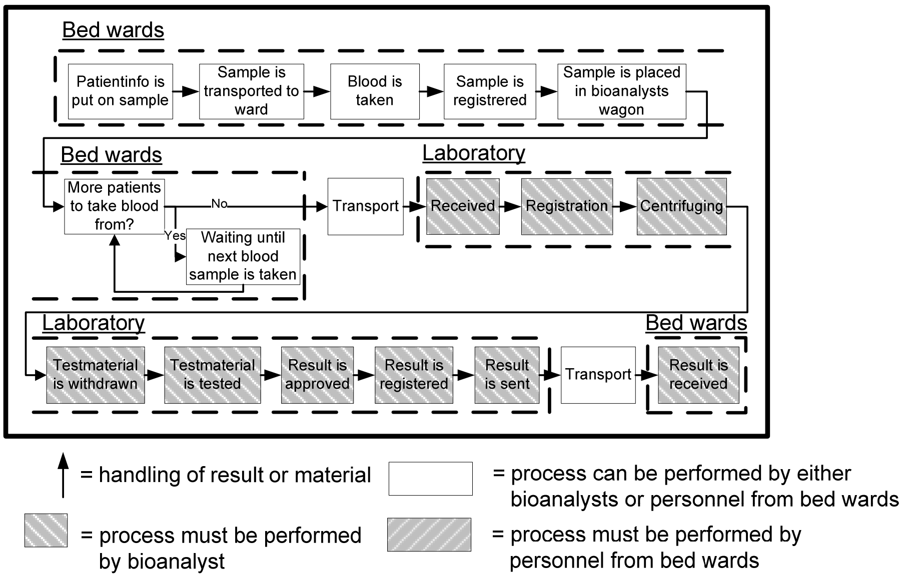

Figure 3: Process map for the blood samples taken at the wards

The major purpose of this system is to secure that the samples are transported as fast as possible back to the laboratory, because too long waiting time can have an undesired effect on the result. Further because of the great amount of samples being analysis, there is a risk of blood samples queuing up in the laboratory.

The hospital consists of 25 different wards where blood samples are taken. The wards are placed within four major parts of the hospital each consisting of two floors. These 4 parts consists of respectively 4, 6, 6 and 5 wards. Further there are 4 additional wards at two different locations.

Data collection

The data used in constructing the two simulations were based on data extracted from the hospital information systems, and from on-site observations of the time spent performing different processes. Further blue prints of the hospitals were used.

- Data extracted from database
    - Arrival of patient from January through March in the emergency department.
    - The time spent from a sample is put onto the conveyor system until the blood analysis data is ready and can be approved.

    - The amount of patients having blood samples taken from each of the wards.
    - Amount of time for taken blood test for each of the wards.
    - Time spent when finishing and leaving a ward.
- On-site observations and interviews:
    - Time spent drawing blood samples at different times of the day, and for different types of patients.
    - The velocity of personnel walking around the hospital.
    - The amount of time spent in each of the waiting positions.
    - Time used when waiting for the elevator and transportation time of elevator.
    - Time it takes to take the elevator.
- Blue print of hospital:
    - Layout of the different floors at the hospital with exact distances.

Simulation construction

The simulation approach used in this research is discrete event simulation. This is due to the many interdependent parameters with a randomly determination, and the tool used has been ProModel.

ProModel gives the opportunity of making a visual simulation of the system, and thereby the possibility of presenting the model to the health care personnel and get a validation of the construction of the model.

Both of the simulations models had focus on the throughput time of the systems, but the start and end times for the simulations were differently based on the differences of the systems. For the emergency case the time spent from a blood sample has been drawn in the emergency department until the result is received again in the emergency department was measured. Further focus was on determining whether any queuing occurred in the system. In the wards case the time from samples are drawn until samples are returned to the laboratory was of interest, as well as the distribution of sample arrivals in the laboratory.

The amount of resources used for each of the different technologies has been decided using the simulation. The decided amount of resources have been chosen when an increase in resources will not lower the throughput time with more than 10 %.

The variable input is the amount of nurses working in the emergency department and the amount of patients in the emergency department.

In both simulations all process times are described using normal distributions.

Results

For the emergency case the major time consumption was experienced during the transportation process between the emergency department and the laboratory, and during the analysis of the blood samples. The analysis of the blood samples is highly automated, so it was determined that it was not possible at the moment to change this process, and therefore the focus was on the processes happening from the blood sample is taken until the analysis is started.

The following technological changes were identified as suitable for performing the process in terms of the quality requirements set up by the hospital, and the physical layout of the hospital. The changes were made into scenarios and a simulation model was constructed representing each of the scenarios.

1. Using two robots to transport the samples between the waiting position at the emergency department and the waiting position at the laboratory.

2. Using a pneumatic tube system to transport the blood samples between the emergency department and the waiting position at the laboratory.
3. Using a pneumatic tube system to transport the blood samples between the emergency department and the laboratory. The samples will be received by a robot that places the blood samples in the conveyor system that is connected with the machines performing the steps of the analysis.

Further it was discussed whether it was possible to move the laboratory or the emergency department so there would be no transportation between the two departments. This was considered as not being possible, and is therefore not a scenario that is explored.

For the wards case the major time consumption was experienced when blood samples have been taken at the beginning of a blood taking round, and is transported with the biomedical analyst during the following part of their route.

The following technological changes were identified as suitable for performing the process in terms of the quality requirements set up by the hospital, and the physical layout of the hospital. The changes were made into scenarios and a simulation model was constructed representing each of the scenarios.

1. Using three AGVs to transport the samples between the wards and the laboratory.
2. Using a pneumatic tube system to transport the blood samples between the wards and the laboratory.
3. Using four porters to transport the samples. The porters goes rounds to the wards every 45 min, and picks up the samples that are ready and transport them to the laboratory.
4. Using three porters to transport the samples. The porters are called upon when blood samples are ready to be picked up.

Testing the scenarios

Each of the scenarios was tested to determine the average and maximum time. The average time is determined as the average throughput time of all the test runs. The maximum waiting time is calculated as the maximum throughput time obtained for the scenario in any test run.

Table 1: Throughput time (in min) from blood samples are taken at emergency department until result is received in emergency department

Scenario	Average	Maximum
Current	87 min	118 min
AGV	74 min	103 min
Pneumatic	60 min	86 min
Pneumatic and robot	51 min	80 min

Table 2: Change in throughput time compared to current situation

Scenario	Average (% change compared to current)	Maximum (% change compared to current)
AGV	-15 %	-13 %
Pneumatic	-31 %	-27 %
Pneumatic and robot	-41 %	-32 %

Table 1 shows the results obtained from the simulations of the different scenarios for the emergency case, and table 2 shows the change of time between the different scenarios and the current situation.

The simulations shows, that either using AGVs or pneumatic tube system will decrease the throughput time both in terms of the average and the maximum. If the hospital decides to implement the pneumatic tube system the potential decrease is 31 % for the average throughput time and 27 % on the maximum time. The hospital can also decide to install a robot that receives the blood samples at the laboratory and the decrease will be 41 % for the average throughput time and 32 % for the maximum throughput time.

The difference between the average throughput time and the maximum throughput time for the alternative scenarios is primarily due to the construction of the simulation. The different process times have been described using normal distributions, resulting in some extreme situations where the process time of all the processes are in the highest part of the bell curve.

The big difference in terms of the current situation is a combination of the processes being described using normal distributions. Blood samples taken in the current situation can however also experience two different extremes in terms of transportation, the samples can be picked up by the porter right after the being taken or it can take up to 30 min.

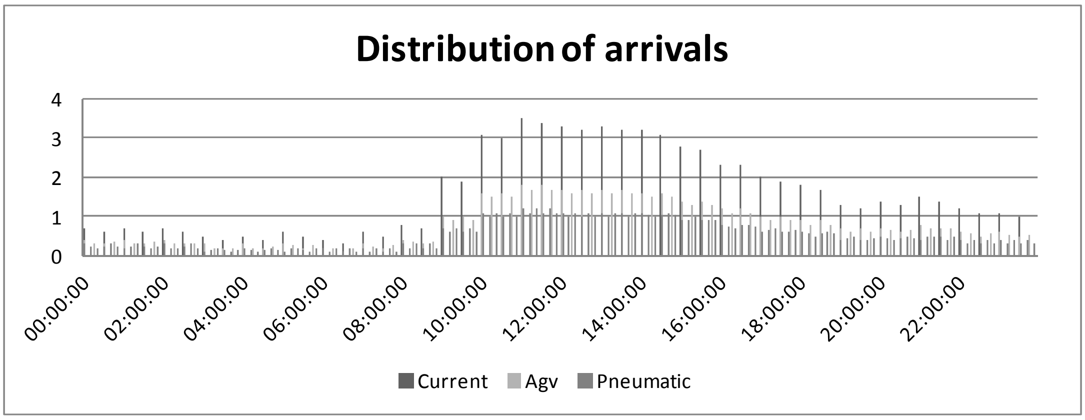

Figure 4 – Distribution of arrivals of blood samples at the laboratory for the emergency case using different scenarios.

Changing the means of transportation will result in a more even distribution of arrivals at the laboratory. The histogram shows that the amount sample in each arrival be approximately halved changing the current situation to using AGVs. The amount of samples with each arrival will also be lowered changing from AGVs to a pneumatic tube system. This is due to the increased amounts of transportations. Because the histograms are constructed using patient data from three months, the arrivals are not whole numbers.

Table 3 – Throughput time (in min) from blood samples are taken at the wards until samples are received in laboratory and the spread in arrivals

Scenario	Average	Maximum	Spread in arrivals
Current	66 min	134 min	1 hr 23 min
AGV	55 min	110 min	1 hr 54 min
Pneumatic	43 min	116 min	1 hr 51 min
Porters going rounds	47 min	142 min	1 hr 22 min
Porters called upon	68 min	128 min	1 hr 49 min

Table 4 – Change in throughput time compared to current situation

Scenario	Average (% change compared to current)	Maximum (% change compared to current)
AGV	-17 %	-18 %
Pneumatic	-35 %	-13 %
Porters going rounds	-29 %	6 %
Porters called upon	3 %	-4 %

Table 3 shows the results obtained from the simulations of the different scenarios for the wards case, and table 4 shows the change of time between the different scenarios and the current situation.

The simulations show that there is a big potential in changing the current procedure of the transportation. The biggest potential in terms of the average throughput time is using a pneumatic tube system that will decrease the average by 35 %. The largest decrease in maximum throughput time is obtained by using AGVs which will decrease with 18 %.

One of the results obtained from the simulation that stands out, is the high maximum throughput for the "Porters going rounds" scenario. This has the explanation, that at some wards the porters have just passed on their rounds, when the biomedical analyst has finished taking samples at that ward, and the samples will therefore wait a very long time, from they have been drawn until they reach the laboratory. Further some of the high maximum throughput times are due to extraordinarily high intake of patients at some of the wards on certain days.

The scenario with the largest spread is shown in table 3. The spread shows that "AGV" scenario has a spread of 1 hour 54 min, whereas "Porters called upon" and "Pneumatic" has respectively 1 hour 51 min and 1 hour 49 min. All of these scenarios perform better than the current situation which has spread of 1 hour 23 min.

Discussion

This paper explores the possibility of using simulation to address the outcome of operational changes in a health care setting. Hospitals are large complex institutions, and it is almost impossible to make simulations covering this complexity. However focusing on only one small part of the hospital, it has proved possible to make a simulation that draws a believable picture of the actual situation. This has been secured by getting the hospital personnel to validate the obtained results. It is however not possible to validate whether the simulations concerning the other scenarios are accurately. This challenge has been addressed by using the experience of other health care institutions who have been working with the proposed technologies.

Although it is important to have a narrow focus when creating a simulation like the one presented in this paper, it is however also important to be sure that all essential aspects have been addressed. How the different departments are connected to one another and how they influence each other, is very difficult for a person outside of the hospital to fully comprehend, with the risk of missing important influences in the construction of a simulation model. Validating the concept and the construction of the simulation model with the hospital personnel has been taken as the approach to handle this obstacle.

Constructing simulations that showed the daily work of health care personnel in a computer model was a new and interesting experience for the personnel at the hospitals. After the initial scepticism from the personnel, they were impressed with the opportunities in simulation models. It was however very important to include the personnel in the phase of coming up with new technologies. The personnel had some very clear ideas and perceptions on the usability of the different technologies. As a consequence some of the results surprised the personnel, but having used the simulation model as the mean of calculating the results, convinced the personnel of the validity.

Aside from exploring the possibility of using simulation in health care setting, the aim of the simulation was to provide two hospitals with an empirical basis for deciding whether to make changes to the current setup. The results from the simulation has been adopted by the hospitals and included in the decision process of determining whether changes should be made to the systems. It is important to state that the simulations were a supporting tool, and the major analysis on whether or not to make the changes was a financial analysis. Both of the hospitals have decided to go ahead with implementing the pneumatic tube system, as a result of the simulations and the financial analysis.

The research only focused on the effect of changing the technology used in performing a process. It is however possible that there is a big potential in using the same technology and merely rethinking the logistical system. Also the full potential of the technologies might not have been obtained in the simulation. This is due to the possibility of modifying processes according to the new technology, which has not been exploited as part of this research, but definitely will be interesting in relation to the implementation of the technologies.

It is important to state the results obtained in this research are only applicable to the cases involved. It is however possible for other hospitals to use the approach described in this paper to test which solution would be the optimal for them.

Conclusion

The research presented in this paper showed that it is plausible to use simulation models as an approach to address operational changes in health care settings. Constructing the simulation model used in this research was a new approach at dealing with logistical challenges in healthcare settings.

Using a simulation gave the hospital managers insight into some problems that they didn't have on beforehand, and it showed some problems that were not considered as problems. It opened up the eyes of the hospital managers of the possibilities of using simulation in this setting. It gave the hospital managers a basis that they had not used before in terms of making their decision in terms of verifying the effect of managerial changes. It was very easy to make changes to the system and the simulation showed its value as an idea generation for the hospital.

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